Amstutz 10/15/81

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MORPHOLOGICAL INVESTIGATIONS OF FIRST-YEAR SEA ICE PRESSURE RIDGE SAILS

by

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ABSTRACT

Sea ice pressure ridge sail heights and the dimensions of ice blocks that comprised the sails were. measured for 30 ridges in April, 1980. The ridges were located from 30 to 200 km offshore in the Prudhoe Bay, Alaska region. Sail height was found to be a function of the thickness of the ice in the ridge. A reasonable relationship shows that height is dependent on the square root of block thickness, The data also verifies that the ratio of sail height to ice block thickness is much larger for ridges composed of thin ice than for those composed of thick ice. Ridge width and cross-sectional area are also found to be related to block thickness. For the largest blocks in the ridge, block surface area is related to thickness squared, as would be expected from plate deflection theory. Examination of lateral variation of height and width along the ridge shows an expected large variation, particularly with height. No geographic variations of individual pressure ridge morphology were discernible from this data, however a laser profile taken during the study period shows that the mean heights and numbers of ridges decrease as the distance from the coast increases.

IN PRESS, COLD REGIONS SCIENCE & TECHNOLOGY

INTRODUCTION

Sea ice ridges have warranted much attention from the engineering community in recent years. This interest has resulted from the desire to explore for and produce petroleum in nearshore Alaskan and Canadian waters. The primary concerns here are the magnitudes of stresses that will be exerted on fixed offshore structures by floating ice ridges and the possibility that grounding ridges may damage subsea pipelines or well heads. Both of these issues are concerned with the actual strength of ridges. In addition, the existence of ridges poses severe hazards to navigation in these regions.

From a scientific viewpoint, the overall rheology of sea ice is dependent upon the amount of deformed ice present. Highly deformed ice has greater strength than undeformed ice, and thus is less susceptible to further deformation. This, in turn, affects the amount of open water and young ice present, which significantly affects the balance of air-sea interactions.

Previous studies (Weeks et al., 1980, Wadhams, 1976, Tucker et al., 1979, Hibler et al., 1974) have statistically characterized the numbers and heights of ridges in the Alaskan and Canadian nearshore areas by using laser profiles of sea ice. Other studies (Kovacs et al., 1973, Kovacs and Mellor, 1974, Weeks and Kovacs, 1970) have addressed the geometry and structure of first-year and multi-year ridges. In these reports on ridge structure, however, little mention is made of the ice block sizes that comprise the ridge. 'This is somewhat surprising, because ridges are piles of ice blocks, and the block size distribution is a factor which undoubtedly affects the overall strength of the ridge.

It is also of general interest to know what thicknesses of ice deform to create ridges. That is, are ridges created only by deforming new ice in leads and cracks or are stresses sufficiently large to cause deformation of older and thicker ice?

Ridges are created by ice deforming under compression, shear or some combination of the two. In the Beaufort Sea, pressure ridges (those formed under compression) appear to be the predominant type, especially seaward of the nearshore shear zone. During formation of a free floating pressure ridge, ice blocks are piled above and below an adjacent ice sheet. The height of the ridge depends on the strength of this host ice sheet, which is loaded with ice blocks until 'bending stresses exceed its strength (Parmerter and Coon, 1972). When the failure occurs the ridge begins to build laterally rather than vertically, and the blocks broken from the parent sheet are incorporated into the ridge. Because critical bending stress depends on ice sheet thickness, we would expect to find a relationship between ridge height and the thickness of deformed ice, assuming sufficient ridge building forces are available. In a one-dimensional modeling study, Parmerter and Coon (1972) found that ridge sail and keel heights were dependent on ice sheet thickness and on strength, where these were treated as independent parameters.

This paper reports on the results of a field study that was undertaken specifically to examine the size and thickness of the ice blocks incorporated into pressure ridges. The primary purposes of the investigation were 1) to ascertain what thicknesses of ice were being ridged in the nearshore region and 2) to establish whether a relationship exists between ridge height and ice block thickness. In addition, several other types of information concerning block sizes, ridge slope angles, ridge width and lateral variation of height and width were collected and are reported on here. We examined only free floating, first-year ridges, as the heights of grounded ridges are determined by different mechanisms (Kovacs and Sodhi, 1980). While we attempted to confine the investigation to ridges formed by compressive forces, "evidence of shearing was noted in several instances.

FIELD STUDY

The field program took place during the first and second weeks of April, 1980. Ridges were sampled from five sites located offshore near Prudhoe Bay, Alaska. Figure 1 shows the location of the sites which were at 33 km intervals from Cross Island along a line running N24°E. This scheme was chosen to assess possible variation with distance from the coast, and because laser profile data over several years existed for this same line. Each sampling site was approximately 3 km square.

Six ridges were sampled from each site. A 1 m height restriction deleted snow drifts and single overthrust blocks from the survey. Ridges were selected by helicopter with an attempt to be random with respect to ridge size and orientation. only "single" ridges were selected. Rubble fields and clustered parallel ridges were omitted. This restriction made ridge selection somewhat difficult at site 1, which was located within the shear zone which is characterized by rubble fields and multiple ridges. These features gave way to single ridges as distance from the shore increased. This contrast is emphasized in Figure 2 which shows aerial phonographs of small areas within sites 1 and 5.

Several measurements were made on the ice after a ridge was selected. Initially, the highest point along the ridge within easy walking distance (< 0.5 km) was located. At this location an angle and distance from the base of the ridge to the peak were recorded for both sides of the ridge. The base of the ridge was considered to be at sea level as evidence of flooding and refreezing was frequently noted. Measurements were corrected for snow cover when necessary. At locations 15 m to the left and right of the high point, the set of measurements was repeated. The total set of measurements provided the height, slope and width for three points along the ridge. In addition to the ridge geometry, the sizes of the largest blocks (largest referring to upper surface area) in the ridge were measured along the 30 m section. The ice thickness and the surface dimensions were recorded for at least six blocks on each ridge. Where the blocks were piled in a manner that made them accessible, more were measured.

Several environmental factors noted in the field program may have influenced the results of this study. One is that there was an unusually large amount of snow cover on the ice (Kovacs, personal communication). As a result, the measurement of block sizes was extremely difficult because of deep snow drifts, except where recent ridging had occurred. Because of the necessity to collect block-size information, the majority of the ridges sampled were the result of recent reformational events (probably within the preceding month).

Another possible influence is that a deliberate effort was necessary to locate ridges containing block thicknesses of less than 1 m. This occurrence partially removes the randomness from the ridge selection process. While our results show approximately 50% of the ridge samples had ice block thicknesses less than 1 m, these were definitely a minority of the ridges existing at this time. This is likely due to the fact that very little open water, and thus thin ice, had been available for ridging within the month preceding the study.

The final abnormal factor noted was that no multi-year ice was observed along the study line. This seemed highly unusual because in other years, a substantial amount of multi-year ice has been observed within a few kilometers of Cross Island (Tucker et al., 1980), however, Kovacs (personal communication) reports that no multi-year ice has existed close to shore in this area for the past three winters. The presence or lack of multi-year ice may possibly affect the morphological characteristics of ridges in a certain area.

RESULTS AND DISCUSSION

Ridge Height vs. Block Thickness

The three height measurements made along each ridge were combined to form a "mean" ridge height. Because the highest local point was included in the measurements, this value is probably biased high. However, without a height measurement at least every meter for the entire length of the ridge, determination of the average height of the ridge becomes subjective. We felt that our measurement technique would provide a consistent method of determining the relative size of the ridge. Block thicknesses were also averaged to provide a mean block thickness for each ridge. An interesting but expected discovery was that not all ridges were composed of a single thickness of ice. Figure 3 shows blocks of different thicknesses in a single ridge. Of the 30 ridges sampled, four contained two distinct block thickness categories, four contained three distinct ice thicknesses, and the remainder were composed of one general thickness. This finding probably implies that thinner ice in refrozen leads was piling on a thicker parent sheet. In these cases we should be comparing our ridge heights to the thickest ice in the ridge for comparison to the results of Parmerter and Coon (1972). Because the majority of the ridges contained only one predominant thickness, and because we believe that these ridges had not reached their limiting heights (discussed lacer), we shall use the mean block thickness for the presentation of most of the results. The largest variation observed in a single ridge were block thicknesses ranging from 0.7 m to 2.13 m.

Figure 4 shows the mean ridge height plotted against block thickness for the 30 ridges. Several interesting features are immediately apparent in Figure 4. First, nearly 50 percent of the ridges measured were composed of ice in excess of 1 m thick. Also, as mentioned earlier, we experienced difficulty in locating those few ridges that were composed of thinner ice. This finding seems to be in contrast with earlier ideas that the majority of ridges will be composed of ice less than 1 m thick (Kovacs and Mellor, 1974). It also differs with observations made by a party on a trans-Arctic surface crossing (Herbert, 1970) who found that 84 per-cent of the ridges measured had slab thicknesses less than 1 m in the Eastern Arctic. Our observation may be anomalous with respect to time or location, however. Since the excessive snow cover limited our sampling to recently formed ridges, a lack of thin ice during this time period would have forced thicker ice to be ridged.

Another obvious feature of Figure 4 is the lack of ridges containing thicknesses between 0.5 and 0.8 m. This is probably due to a combination of events including snow cover concealing ridges of this thickness, lack of recent ridging activity and coincidence.

Probably the most interesting aspect of Figure 4 is the relationship between the ridge height and block thickness. It is obvious that the correlation is not high, but a large amount of scatter is somewhat expected if one considers that ridge building forces vary between different ridging events. Ridge height is certain to depend on the force available and its active duration as well as the strength and thickness of ice. If the available force or duration is less in some cases than others, the height would be expected to fall short of the limiting maximum height.

A reasonable fit to the data in Figure 4 as shown is

$$h = 3.69\ t^{1/2} \quad (m) \tag{1}$$

where h is ridge height (m) and t is ice block thickness (m). While a linear or exponential curve may fit the data better in a statistical sense, the square root law seems more appropriate because it allows height to go to zero with thickness. This approach is consistent with a ridge redistribution function proposed by Hibler (1980) as part of a variable thickness sea ice model. The square root relationship can be derived with simple geometrical arguments by making several assumptions. This derivation is carried out in the Appendix.

The ridge heights predicted by Parmerter and Coon (1973) using fracturing strengths (σc) of $2.0 \cdot 10^6\ Nm^{-2}$ and $3.5 \cdot 10^5\ Nm^{-2}$ are also shown in Figure 4. Their predicted heights for the two strengths nearly envelope our observed heights. This is a very encouraging result which gives credence to the Parmerter and Coon model. A relevant point however, is that the predicted ridge heights are of limiting heights for various parent sheet thicknesses and should represent the maximum heights attainable. For this case, a better comparison to the Parmerter and Coon model is to plot the observed ridge heights against the maximum block thickness found in each ridge, which should represent the thickness of the parent sheet as mentioned earlier. Figure 5 shows this, and as expected, several more heights fall below the high strength limiting height prediction. A square root relationship works reasonably well here also, but we choose to restrict regression fits to mean block thicknesses for reasons mentioned earlier and because the geometrical arguments which help justify the square root law (Appendix) are not concerned with the parent sheet thickness.

That several observed heights are larger than the Parmerter and Coon predicted values may indicate a high bias in our observations due to the use of the highest local point for one of the three height measurements. Comparison of the mean heights from each site to those derived from laser profiles in the same area shows our ridge measurements to be 1.7 m higher on the average. Relative to the laser profiles, our sampling was certainly biased towards higher ridges. However, the mean ridge height derived from laser profiles is very sensitive to the low height cutoff (1.0 m) because there are so many small ridges. Thus our heights in this study may be high by laser height standards, but they are not anomalously high. In any case it appears that only a minor increase in the fracturing strength in the model or a better technique for representing the mean height of a ridge would make the predictions and observations even more compatible.

Parmerter and Coon (1972) found another interesting model result in that the ratio of ridge height to ice thickness was much larger for thin ice. Tnis is also apparent in our observations and can be deduced from Figure 4. Figure 6 shows this result much more clearly, however, where ridge heights are normalized by mean block thickness. Here ratios of 6 to 15 are evident for 0.2 to 0.3 m ice while ratios of only 2 to 5 exist for ice in excess of 1.0 m. Our best empirical fit to this data using a square root relationship as found previously is

$$h/t = 4.23/t^{1/2}. \qquad (2)$$

This curve is also shown in Figure 6, along with the Parmerter and Coon (1973) model predictions for the two fracturing strengths. As expected, their predicted values for the highest strength case match our observations quite well. The use of maximum block thickness causes more points to fall below the high strength prediction but is not shown here.

Ridge Width, Slope and Area

The width of the ridge base can also be shown to be proportional to the square root of ice thickness if we use the same simple geometrical assumptions as presented in the Appendix. The energetic approach however, says that the ridge should begin to build laterally once the limiting height is reached. If the limiting height is reached in most ridges, no relationship between ridge width and ice thickness should be apparent.

The ratios of width to block thickness versus block thickness are shown in Figure 7. Obviously, there is reasonable correlation between witch and thickness. The data demonstrate that, similar to height, the width can be many more times the thickness of thin ice than for thicker ice. Once again, a reasonable fit to the data is obtained using a square root law in the form of:

$$w/t = 17.05/t^{1/2} \tag{3}$$

where w is the width of the ridge base (m).

That width is so obviously related to thickness leads to the conclusion that the ridges sampled in this study had not reached their limiting heights, and thus had not begun to build laterally. This is somewhat verified by the fact that we selected only "single" ridges for this investigation. This inherently limits the possibility of having ridges which had reached their limiting heights. Free floating multiple ridges and rubble fields are examples where lateral building has definitely taken place. These features should be investigated if limiting heights alone are of interest.

Our measurements showed the mean ridge slope angle to be 26.11°. The maximum and minimum angles were 51.34° and 8.77° respectively. These angles compare well with Kovacs (1972) who reported that first-year ridge slope angles vary beteen 10° and 55" with a mean of 24° and with Wright et al. (1978) who reports a mean slope angle of 25°. Figure 8 shows the height versus width for the 30 ridges along with the 26.11° slope angle line. Here it is apparent that the scatter of slope angles is relatively small. This lends support to the constant slope angle assumption used to derive the square root relation in the Appendix. Further investigations proved that slope was independent of block thickness.

Because 'both ridge height and width correlate reasonably- well with thickness, it follows that similar behavior may be expected of cross-sectional area. Figure 9 shows cross-sectional area versus block thickness. The relationship here is not as apparent as with height or width, particularly with the larger thicknesses. From equation (A-3), we would also expect a linear relationship to exist. The best fit line passing through the origin is:

$$A = 29.76t \quad (m^2) \tag{4}$$

which is also shown in Figure 9.

That the data points are not tightly grouped might be anticipated. First, cross-sectional area is dependent on two variables (height and width) which are at best only partially dependent on thickness. In addition, as a ridge is a more or less chaotic arrangement of blocks which is roughly triangular in cross section, area may be a highly variable quantity. Combining these reasons with the previously mentioned concern over variable ridge building forces leaves little doubt that a large scatter of the data is to be expected.

Block Area

Measurements which enabled the calculation of the top surface area of the blocks were also made during the field study. This quantity simply expresses the size of the block without involving the thickness dimension. In general, our measurements included the largest of the blocks in the ridge. Because pressure ridges consist of blocks ranging from some limiting size down to very small pieces, variation among ridges will be with the larger blocks.

The block areas were combined to form a mean for each ridge and are shown as a function of thickness in Figure 10. The best empirical fit to this data is

$$a = 0.67\ e^{1.86t}\ (m^2) \tag{5}$$

where a is the block area (m^2). Because critical bending moment is related to the thickness squared for simple beam theory (Parmerter and Coon, 1973), we might expect that cross-sectional area would also be related to thickness squared. The best fit to thickness squared is

$$a = 4.48\ t^2 \qquad (m^2) \tag{6}$$

and is also shown on Figure 10. This relation does not fit the data as well as the exponential given in equation (5), particularly for the lower thickness categories perhaps because different mechanisms or ice properties govern failure at small thicknesses. The exponential fit is purely empirical, and it does not allow the block area to approach zero with the thickness. Either curve seems adequate for thickness greater than 0.6 m.

Lateral Variation of Height and Width

We are able to examine limited aspects of the lateral variation of height and width insofar as our three measurements per ridge permit. These results may be of interest to users of spot remote sensors such as laser profilometers and to those using statistical ridge models for off-shore structure design purposes. Hibler and Ackley (1975) previously reported on the lateral variation of height using shadow lengths to provide heights every 5 m. They found an average variance of 0.46 m^2 for eight ridges, each approximately 1 km in length. We found an average variance of 0.48 m^2 over the 15 m interval combining all measurements. The similarity between these independent results indicates that height variation is indifferent to sampling intervals between 5 and 15 m.

Perhaps even more meaningful results are shown in Table 1. Here we have "given the mean and maximum variations of height and width referenced to the center values of each ridge.

Height variation seems particularly high. It is even more impressive when one considers that average ridge heights given by laser profiles are between 1.2 and 1.8 m (Tucker et al., 1979). These large variations over relatively short distances emphasize the fact that ridges are highly variable piles. of blocks. They also imply that a single cross-section measurement to represent an entire ridge should be treated with caution. In further examinations, we found no substantial relationship between block thickness or area and percent lateral variation, although, in general, the largest variations occurred on the largest ridges (which are inherently composed of the largest blocks).

Geographic Variations

Where feasible, figures have had data points plotted by sampling site. The only geographically related feature seems to be that the three largest ridges were located in site 1. Because the sampling scheme was subjective and because only a limited number of ridges were measured, this finding is probably coincidence. For these same reasons, recognition of other characteristics related to geographic location is rather speculative.

Figure 2, which shows the aerial photographs of sites 1 and S, makes it clear that many more ridges exist closer to shore. This is verified in Figure 11 where laser profile ridge height and density counts taken during the time of our field study are shown. Also shown are data from previous years for this same Cross Island line (N24°E). A general decrease in the number of ridges and in the mean ridge height as distance from shore increases is indicated. This decrease in mean height is apparent for both the March 1978 and April 1980 laser runs and is contrary to previous findings by Tucker et al. (1979) that mean height remained essentially constant with distance from shore.

In general then, our investigation found no obvious morphological differences related to ice thickness or block size that could be attributed to geographic location. If such variations exist, a more objective sampling scheme would be necessary to resolve them. Of major importance would be the requirement to sample more ridges from each site.

General ridging characteristics do vary with distance from shore as evidenced from the laser profiles. The prevalence of many more shear type ridges near shore also has been reported previously (Kovacs and Mellor, 1974, Tucker et al., 1980) and can be deduced from Figure 2. As mentioned previously this investigation concentrated only on pressure ridges. We do not know whether the presence of multi-year ice in the nearshore area would create discernable morphological differences in these pressure ridges.

CONCLUSIONS

The following conclusions concerning the structure of first-year pressure ridge sails are suggested by this study of ridge morphology in the nearshore region.

1. Ice in excess of 1 m in thickness commonly deforms to form pressure ridges. The degree to which this occurs depends on the amount of thin ice available (as this will deform first) and the ridge building force.

2. Ridges are occasionally composed of two or three distinct ice thicknesses which may vary by more than 1.0 m.

3. This study supports the results of Parmerter and Coon (1972) who found through modeling studies that sail height is partially dependent on the thickness of ice being ridged. In general, sail heights appear to scale with the square root of ice thickness. Ridges of thin ice can be many times as high as the thickness of the ice that is ridged while those composed of thicker ice (> 1 m) are only 3-5 times the thickness.

4. Ridge width is also partially dependent on the thickness of ice being deformed. Width is also a function of the square root of ice thickness provided ridges have not begun to grow laterally after the limiting height has been reached.

5. Cross-sectional area is a linear function of ice thickness, but the relationship is not as apparent as with width or height.

6. Ridge slope is independent of block size and thickness. Slope angles vary from 8 to 52° with a mean angle of 26°.

7. Maximum block area (topside surface area) is dependent on block thickness.

8. Obtaining a representative ridge profile with one cross section is a recognized problem. This is emphasized by our lateral variation findings in which the mean variation over 15 m was 28% for height and 14% for width.

9. Morphological differences related to block size attributed to distance from shore were not discernible in this study. More and higher ridges occurred closer to the coast and more shear type ridges were evident near shore.

Acknowledgements

This work was supported by funding from the Bureau of Land Management through interagency agreement with the National Oceanic and Atmospheric Administration under which a multiyear progrsm responding to needs of petroleum development of the Alaskan continental shelf is managed by the Outer Continental Shelf Environmental Assessment Program (OCSEAP) Office. This study was accomplished under Research Unit #88. We also acknowledge the valuable technical comments provided by W. Weeks, W.D. Hibler III, A. Kovacs, D. Sodhi and an anonymous reviewer.

APPENDIX

RIDGE HEIGHT GEOMETRY MODEL

Hibler (1980) proposed a maximum height for a ridge redistribution function which scales with the square root of the thickness of ice being ridged. By making several assumptions ridge heights can be shown geometrically to be functions of the square root of ice thickness. Consider that the statistical distribution of lead widths is independent of the ice thicknesses in the leads. Then assume that equal width leads containing different ice thicknesses undergo ridging. Also assume that slope angles, top and bottom, are similar for all ridges and that the ridges are floating freely in isostatic equilibrium.

The cross-sectional area A of the sail of each ridge is given by

$$A_s = \frac{h^2}{\tan\Theta} \quad . \quad (m^2) \tag{A-1}$$

where Θ is the topside slope angle. If the slope angles are equal for the ridges then

$$A_s = \alpha h^2 \quad (m)^2 \tag{A-2}$$

where α is the constant $\frac{1}{\tan\Theta}$.

If the voids in the ridges are neglected, the cross-sectional area of each ridge (top and bottomside) can also be expressed as

$$A = Wt \quad (m^2) \tag{A-3}$$

where W is the original width of the ice that deformed.

Since the topside area will be some fixed fractional amount (k) of the total ridge cross-sectional area,

$$A_s = kA \qquad (m^2) \tag{A-4}$$

then from (A-3)

$$ah^2 = kWt \qquad (m^2) \tag{A-5}$$

and, as assumed earlier, if the widths of the original leads are equal,

$$h = kt^{1/2} \qquad (m) \tag{A-6}$$

after combining constants.

This simplistic geometrical approach makes several assumptions which are not quite valid. The lack of voids can be accounted for by simply assuming a fixed proportion of ridge volume to be void space and including another constant to account for this. Slope angles measured in this study and others (Kovacs 1972, Wright et al. 1978) vary, but seem to be fairly tightly grouped around 25-26°. The most invalid assumption in this geometrical argument is that of equal width leads that deform to become ridges. We feel, however, that lead widths, as with ridge heights and slope angles, must have a statistical distribution which is independent of ice thickness in the leads. If this is true, there will be a predominant range of lead widths that undergo ridging, and hopefully that range is small enough to be included in a constant as done above. We also know that ridge heights will depend on the overall stresses and strength of the ice which is only partially related to thickness. In spite of the large possibility that our assumptions are invalid, this intuitive geometrical model appears to fit the data quite well as shown in Figure 4.

Table 1. Lateral Variation of Height and Width Over 15 m Horizontal Distance.

	Mean Variation (m)	Mean % Variation	Maximum Variation (m)	Maximum Variation %
Height	1.04	28.2	3.2	54.2
Width	2.02	14.2	7.5	31.4

FIGURE CAPTIONS

Figure 1. Ridge sampling locations. Each site was approximately 3 km square.

Figure 2. Aerial photographs of typical ice conditions near site 1 (top) and site 5 (bottom).

Figure 3. Ridge containing two distinct ice thicknesses. Foreground block (being measured) is approximately 0.4 m thick while background block is greater than 1.0 m.

Figure 4. Ridge height versus mean block thickness. Best fit square root curve and Parmerter and Coon (1973) predictions are also shown.

Figure 5. Ridge height versus maximum block thickness along with the Parmerter and Coon (1973) predicted ridge heights.

Figure 6. Ratio of ridge height to mean block thickness versus mean block thickness. Best fit square root curve and Parmerter and Coon (1973) predictions are also shown.

Figure 7. Ratio of ridge width to mean block thickness versus mean block thickness. Best fit square root curve is also shown.

Figure 8. Ridge height versus ridge width along with the mean slope angle line of 26.11°.

Figure 9. Ridge cross-sectional area versus block thickness along with the best fit line passing through the origin.

Figure 10. Block area versus mean block thickness. The best fit exponential and square root curves are also shown.

Figure 11. Mean ridge height (top) and number of ridges {bottom) per 20 km interval for April, 1976, March, 1978 and April, 1980. Values are plotted at the center of the 20 km interval.

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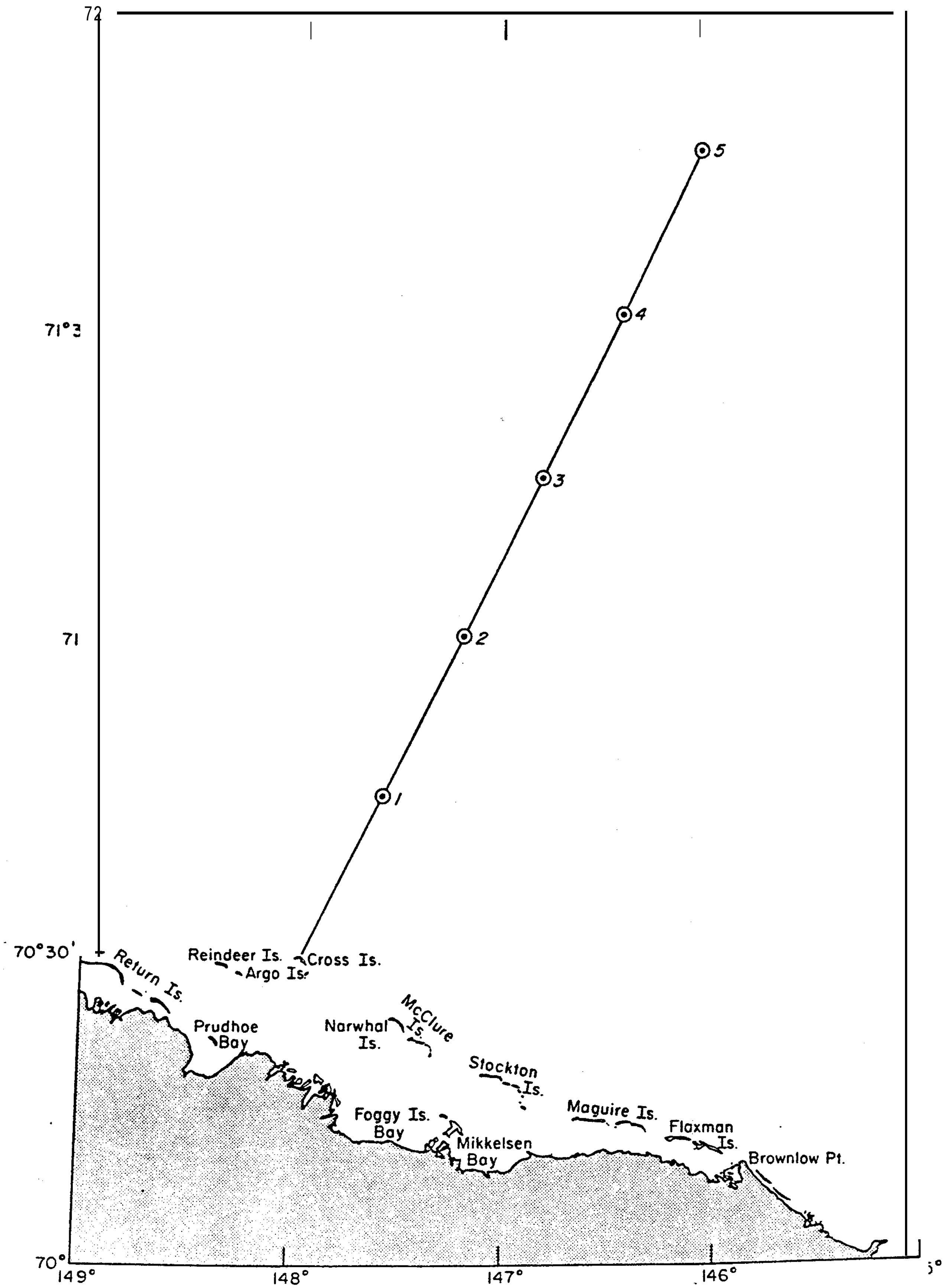

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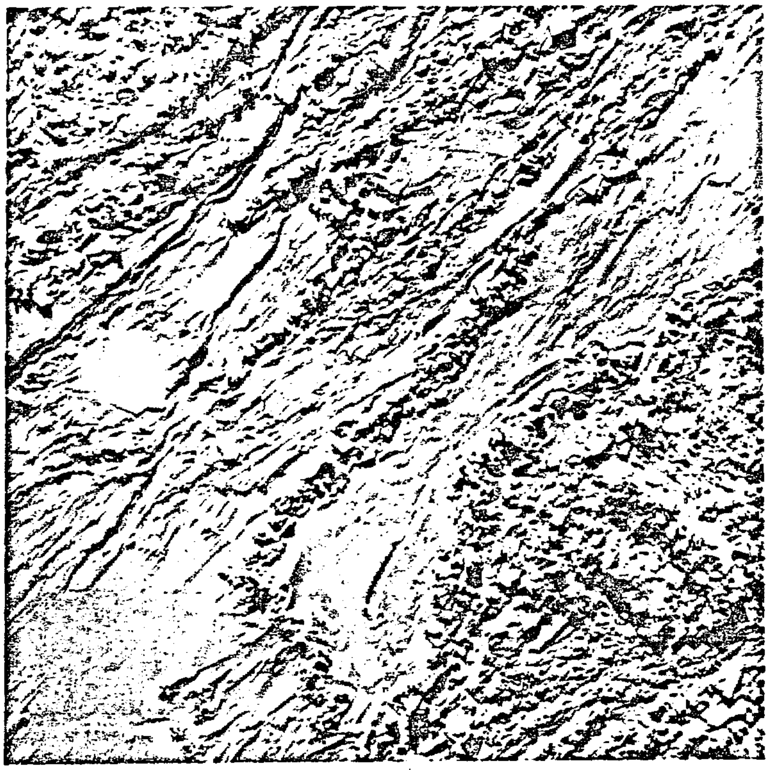


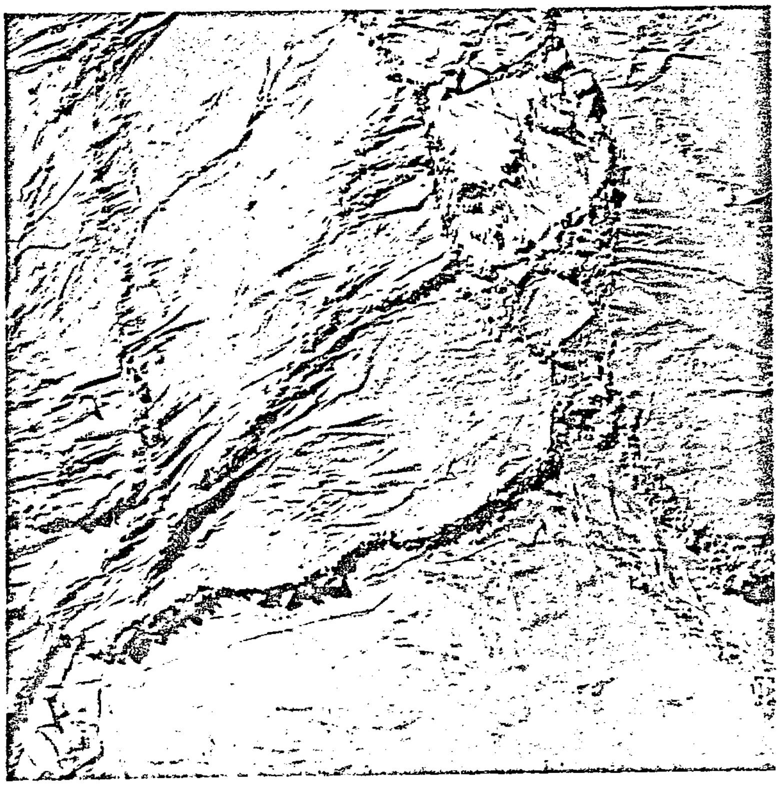


Figure 2. Aerial photographs of typical ice conditions near site 1 (top) and site 5 (bottom).

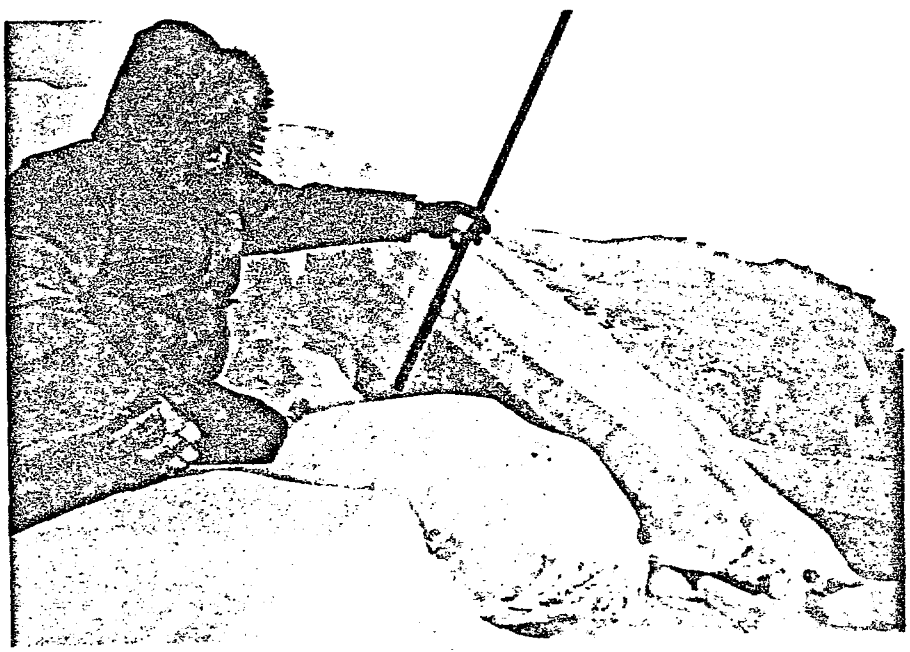
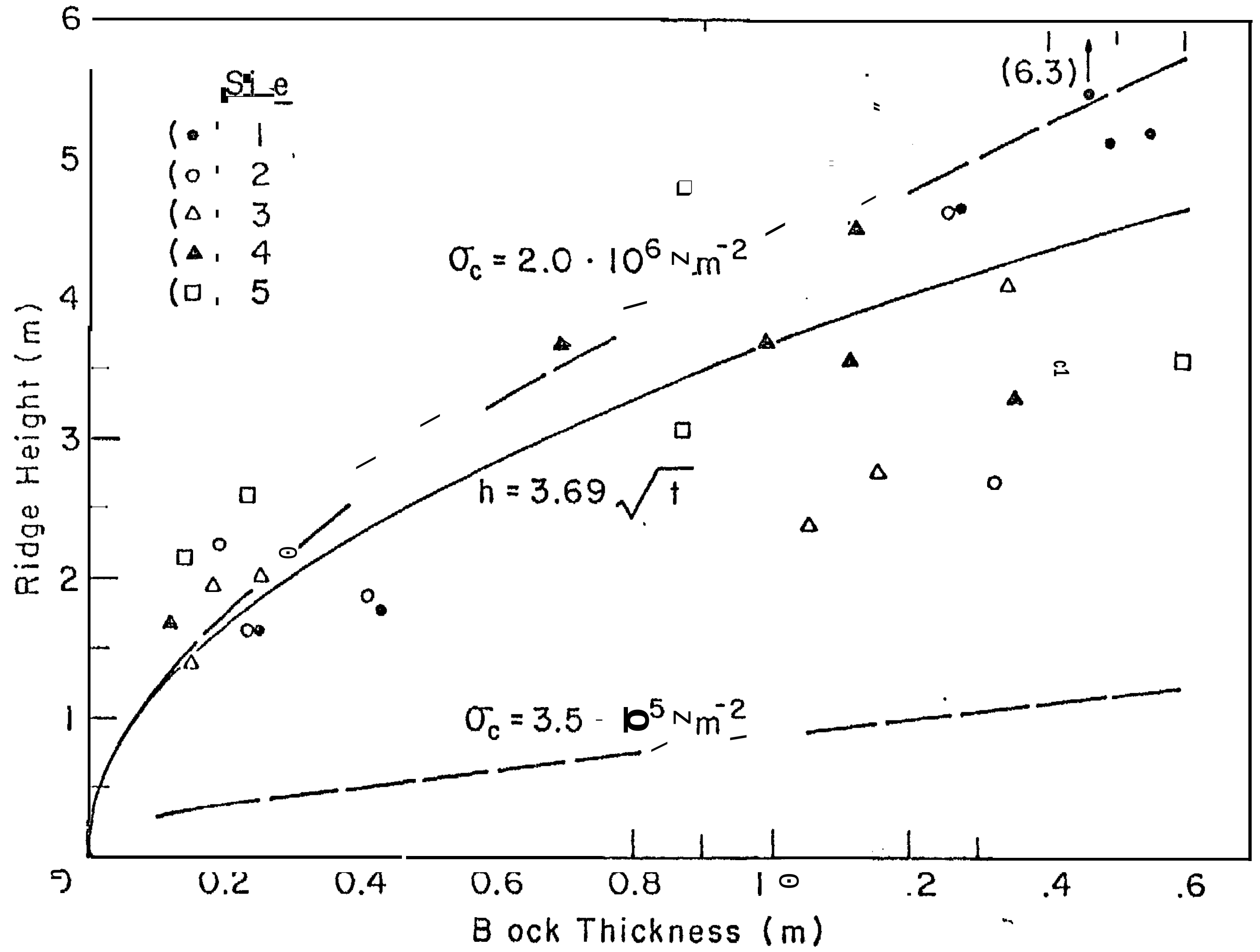


Figure 3. Ridge containing two distinct ice thicknesses. Foreground block (being measured) is approximately .4 m thick while background block is greater than 1.0 m.



mean

Figure 4. Ridge height versus mean block thickness. Best fit square root curve and Parmerter and Coon (1973) predictions are also shown.

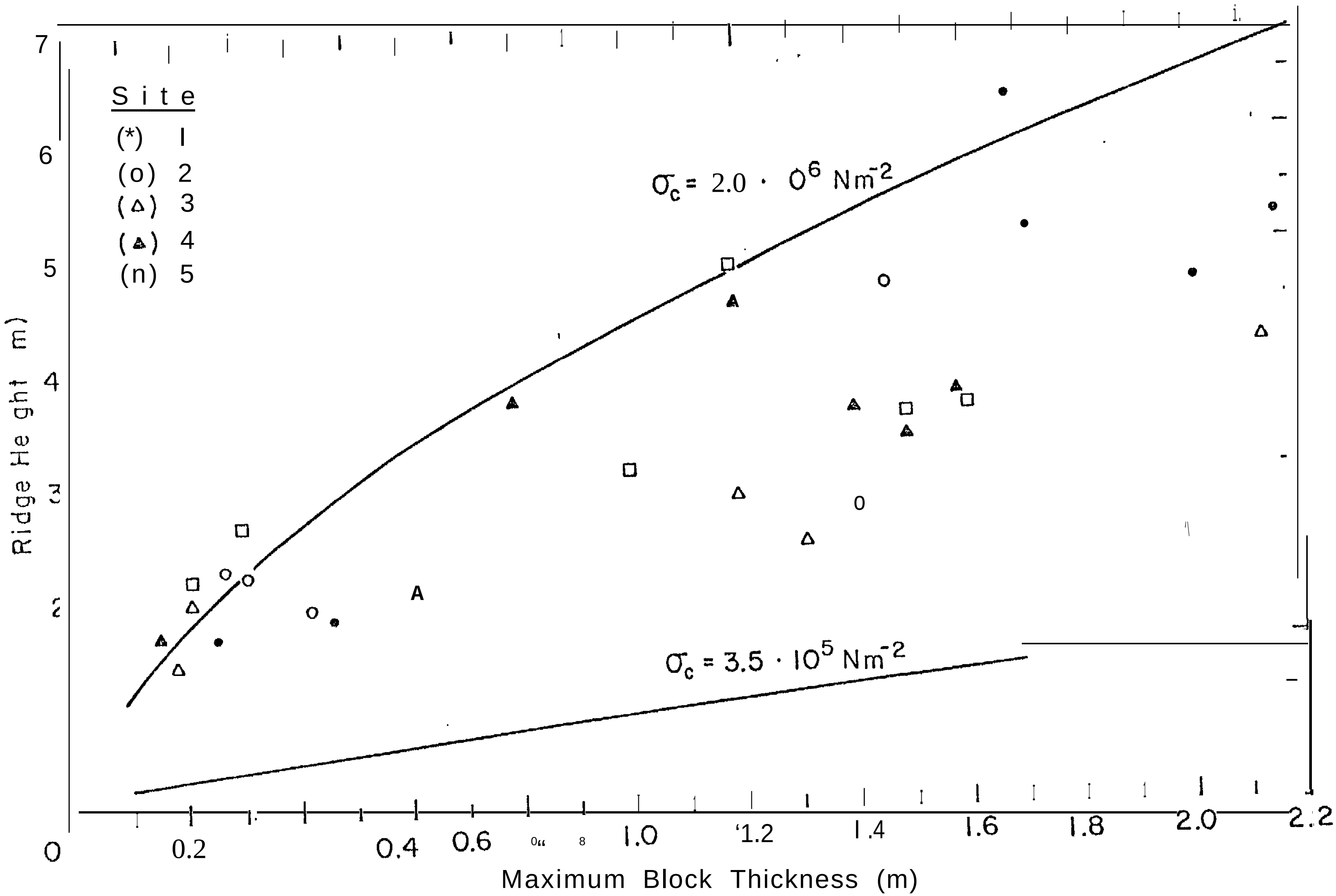


Figure 5. Ridge height versus maximum block thickness along with the Parmerter and Coon (1973) predicted ridge heights.

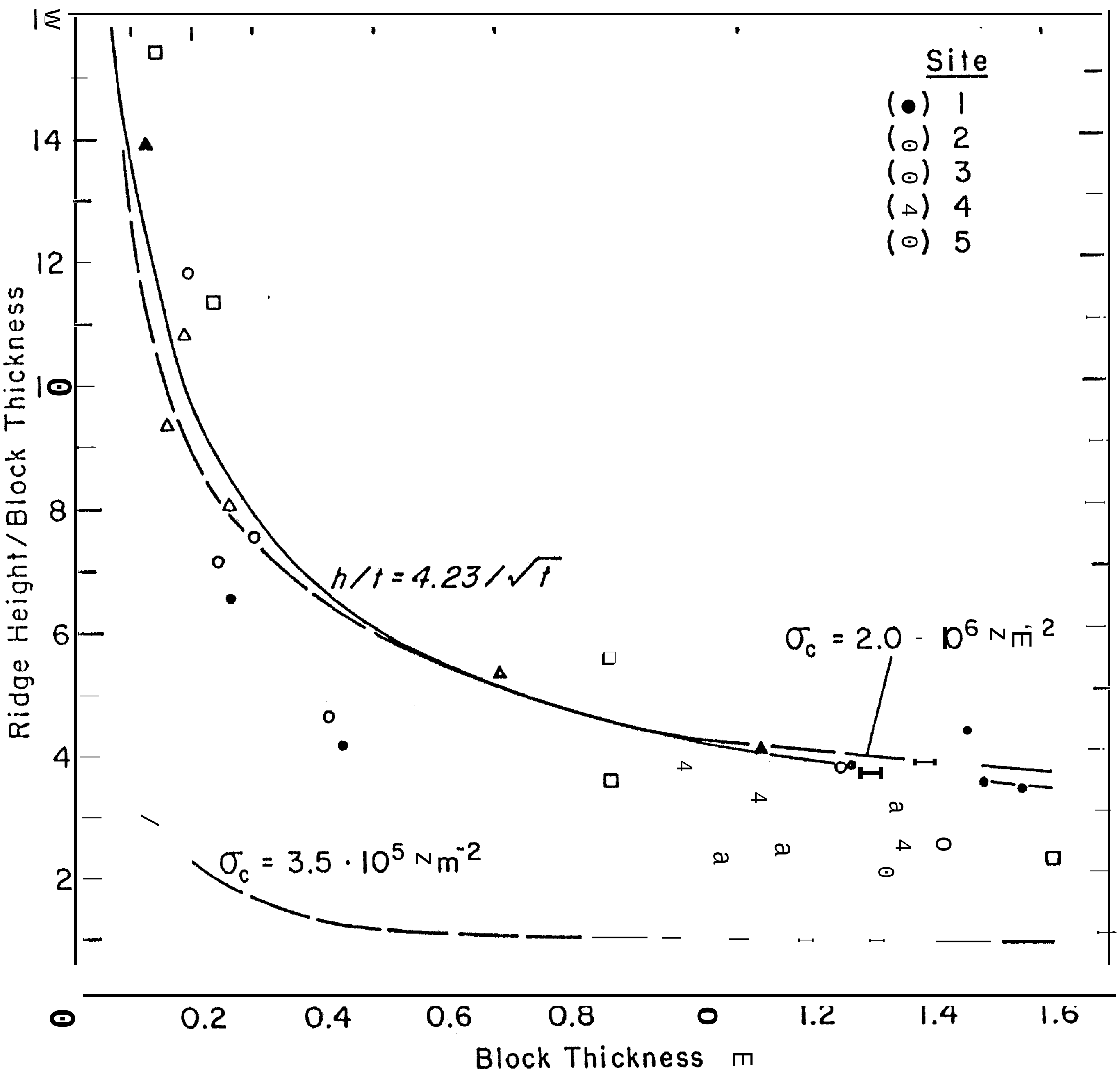


Figure 6. Ratio of ridge height to mean block thickness versus mean block thickness. Best fit square root curve and Parmerter and Coon (1973) predictions are also shown.

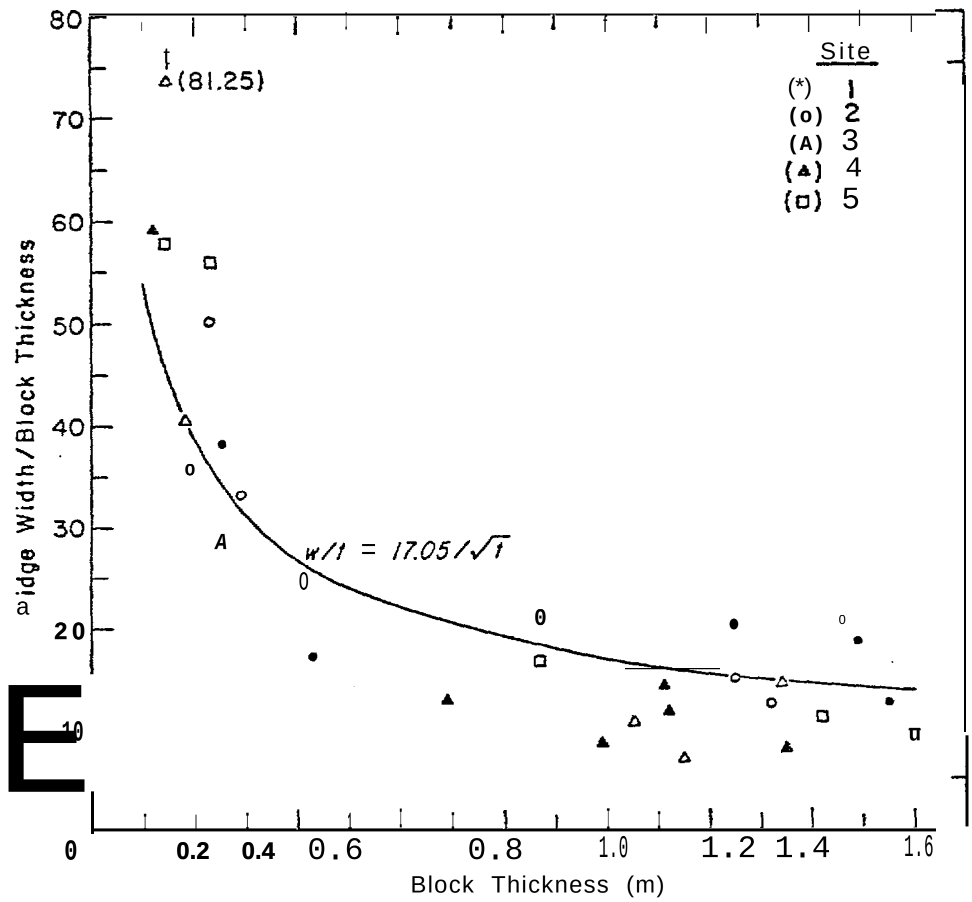


Figure 7. Ratio of ridge width to mean block thickness versus mean block thickness. Best fit square root curve is also shown.

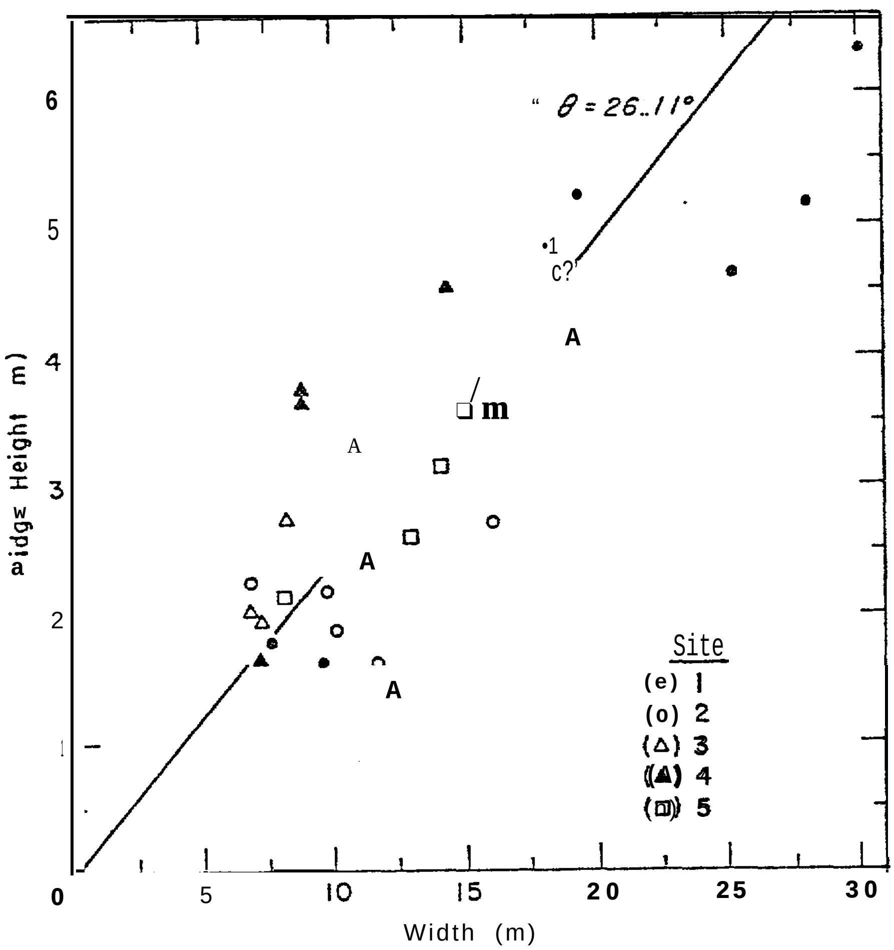


Figure 8. Ridge height versus ridge width along with the mean slope angle line of 26.11°.

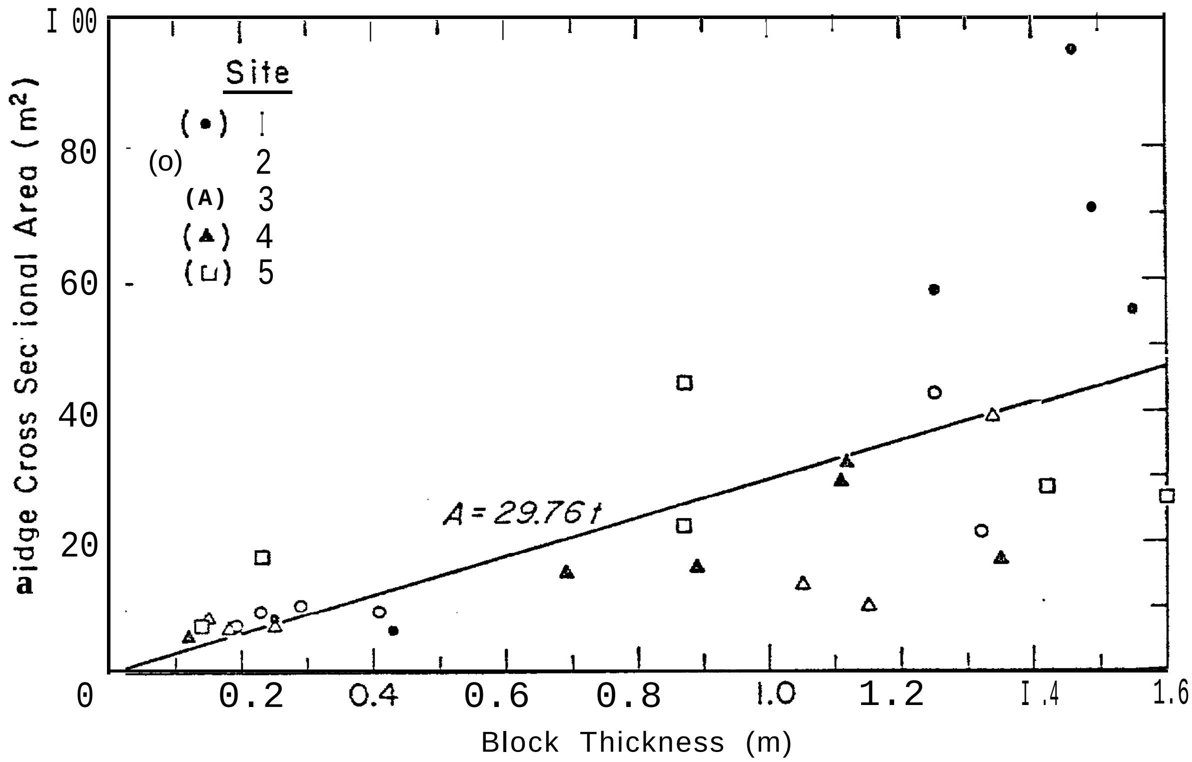


Figure 9. Ridge cross-sectional area versus block thickness along with the best fit line passing through the origin.

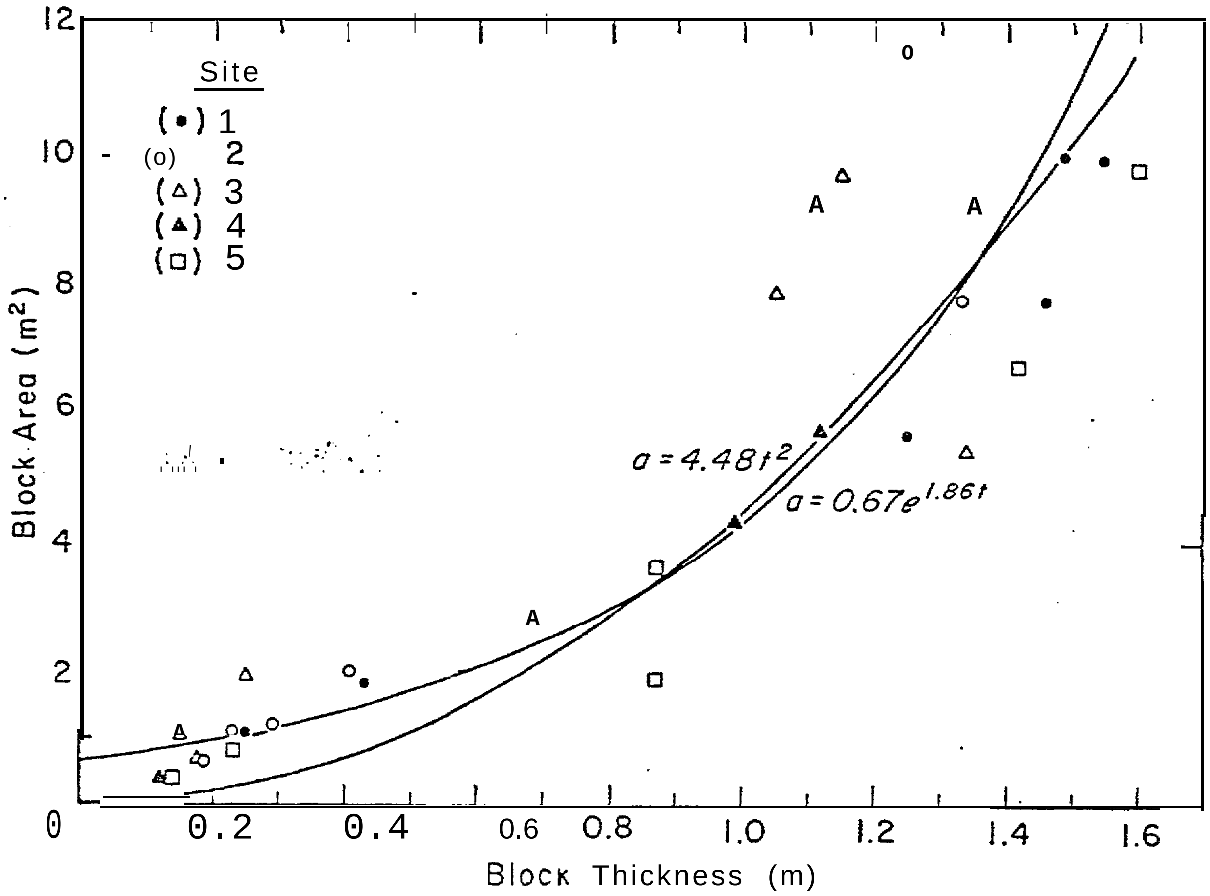


Figure 10. Block area versus mean block thickness. The best fit exponential and square root curves are also shown.

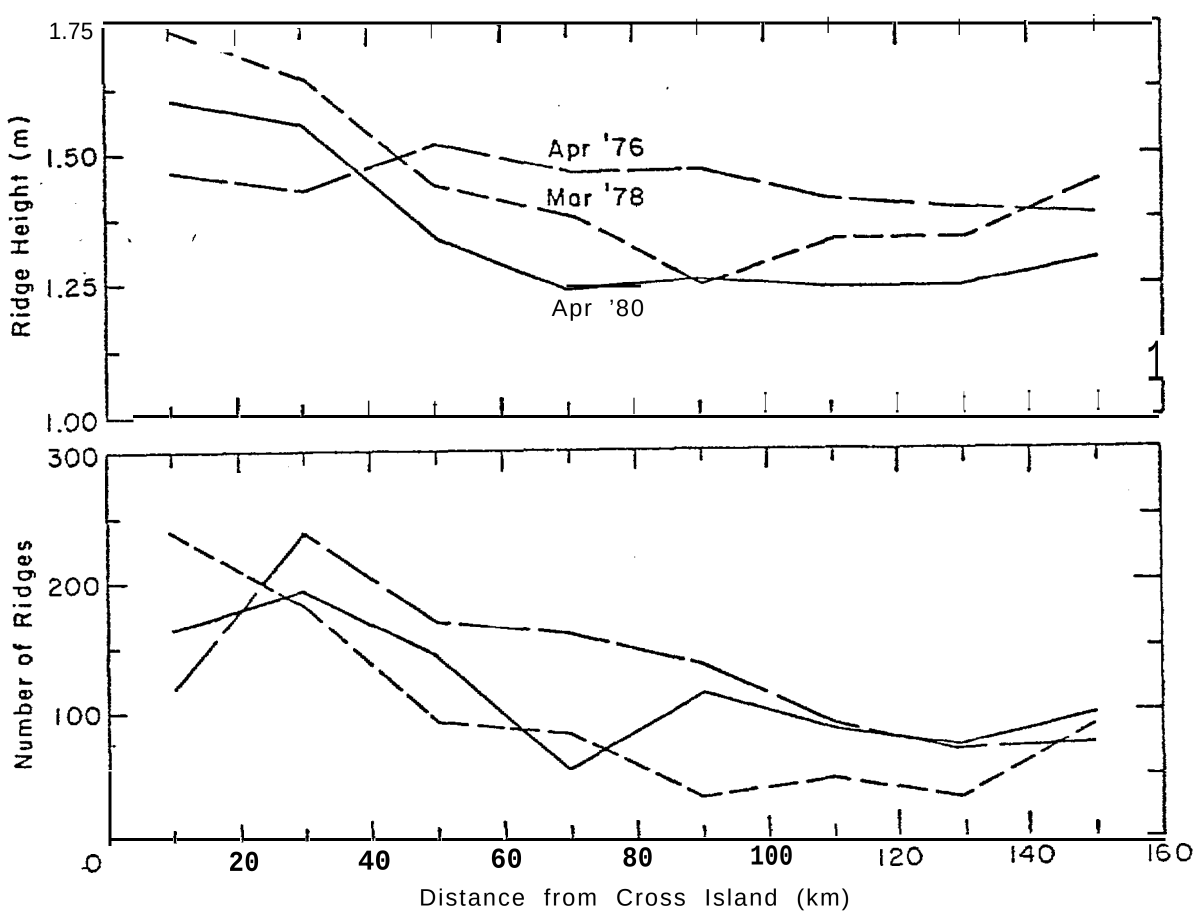


Figure 11. Mean ridge height (top) and number of ridges (bottom) per 20 km interval for April, 1976, March, 1978 and April, 1980. Values are plotted at the center of the 20 km interval.